(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 312 261 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: 23.03.94 (51) Int. Cl.[5]: H04N 5/20

(21) Application number: 88309357.7

(22) Date of filing: 07.10.88

(54) Linearity adjusting circuit.

(30) Priority: 10.10.87 GB 8723874

(43) Date of publication of application:
19.04.89 Bulletin 89/16

(45) Publication of the grant of the patent:
23.03.94 Bulletin 94/12

(84) Designated Contracting States:
AT BE CH DE ES FR GR IT LI LU NL SE

(56) References cited:
EP-A- 0 149 319
US-A- 3 277 318

JOURNAL OF THE SOCIETY OF MOTION PICTURE AND TELEVISION vol. 93, no. 5, May 1984, SCARSDALE US, pages 488 - 491; Favreau et al.: "Adaptive contrast corrector using real-time histogram modification"

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Description

This invention relates to a linearity-adjusting circuit for adjusting, usually correcting, the rate of change of amplitude of an output signal with respect to the amplitude of an input signal from which the output signal is derived. In most applications, the output signal amplitude is nominally proportional to the input signal amplitude. The invention is particularly useful, for example, in a high frequency pre-distortion circuit for signals which are to undergo amplification in power amplifiers, such as klystrons which are used in television transmission. Klystrons, and indeed many high power amplifiers and the like, introduce undesirable signal distortions, and a linearity-correcting circuit is required for ensuring a linear amplitude relationship between the envelope of the modulated and power-amplified transmission signal and the video input signal which was used in the initial modulation process.

In some existing colour television transmitter chains, an appropriate pre-distortion is introduced into the intermediate frequency signal before the waveband-dependant radio frequency stage, for linearity correction. To obtain the correct amount of pre-distortion over the full amplitude range, variable impedances or other elements of the pre-distortion circuit are adjusted manually until the envelope of the transmitted signal has a sufficiently linear relationship with the envelope of the input modulated signal, over the entire range of envelope amplitudes. Since the characteristics of the transmitter chain vary in operation with supply voltage levels and ambient temperature amongst other things, it is found that re-adjustment of the circuit elements is necessary quite frequently. If the non-linearity occurs only over a narrow band of amplitudes, it is found that adjustment of just one circuit element may be sufficient to correct this particular non-linearity, but that it then introduces non-linearities at other amplitude levels. Consequently, even for a slight correction, it is necessary to adjust more than one of the circuit elements. Moreover, because of the interdependence of the settings of the circuit elements, they frequently require more than one adjustment to compensate for each change in power-amplifier characteristics; considerable skill and experience is required in order to judge the degree of adjustment required.

One such system is shown in US patent no. US-A-3277318 which employs resistors to adjust amplitude bands. The characteristics of the resistors are as defined by Ohms law, so as the voltage across a resistor is increased the current flowing through it also increases. As a result the system of US-A-3277318 will suffer from the problem that switching in a resistor to correct the gain of the system at one amplitude band, as is done in US-A-3277318, will also alter the gain of the system at all other amplitude bands because as the voltage is increased the current will increase as well and will effect the gain of the system.

Another such system is shown in European Patent Application No. EP-A-0149319 which also employs resistors and so will suffer from the same problems as US-A-3277318.

The purpose of the present invention is to provide a linearity-adjusting circuit which is capable of automatic control, i.e. without the need for manual adjustment; such a circuit may then be used in a transmitter chain under microprocessor control, in response to an automatic and periodic monitoring of the transmitted signal resulting from test signals. It was considered that, with existing hardware, any software solution to the problem would require a substantial computing capability to implement, and that changes in the hardware might render the software solution much simpler.

The invention provides a linearity-adjusting circuit for adjusting the rate of change of amplitude of an output signal with respect to the amplitude of an input signal from which the output signal is derived (the output signal amplitude preferably being nominally proportional to the input signal amplitude) comprising, for each of several bands of the input signal amplitude, means for selectively introducing a differential voltage to the output signal amplitude over that amplitude band, such that the mean rate of change is changed accordingly only over that amplitude band, and control means for selecting over which amplitude bands to introduce such differential voltages and for determining the magnitudes of such differential voltages, to achieve a predetermined linearity variation for the whole amplitude range.

The invention enables the gain of any amplitude band of a transmitter chain to be adjusted (usually by way of correction) independently of the other amplitude bands, so that the variation of gain in that amplitude band does not itself introduce gain variations in other amplitude bands which would then require correction also. This independent treatment of the various amplitude bands allows the said control means to be automated much more simply, and it may for example comprise a microprocessor control unit.

In another aspect, the invention provides a transmitter chain comprising a linearity-correcting circuit according to the first aspect of the invention described above, means for detecting the amplitude of the transmitted signal, and control means responsive to the said detecting means for setting the levels of the said differential voltages so as to introduce an appropriate pre-distortion to correct the linearity. In use, colour television transmitters,

for example, transmit an inserted test signal, in each frame, modulated with an envelope in the form of a staircase. Using such a test signal, the detecting means of this aspect of the invention demodulates and then differentiates the staircase signal to provide a series of narrow pulses whose heights are nominally equal. The heights of the pulses are compared with a predetermined value representing the height they should be for correct linearity at that particular amplitude band. In response to this comparison, the control means sets the level or levels of differential voltage required for correction over the or each respective amplitude band. The linearity-adjusting circuit thus compensates for the detected non-linearity by introducing the appropriate pre-distortion. Such corrections may be carried out regularly and frequently, so that the transmitter chain is capable of responding quickly to changes in the characteristics of the transmitter due to temperature or supply voltage fluctuations.

Two ways in which the invention may be performed will now be described, by way of example only, with reference to the accompanying drawings, of which:

Figure 1 is a circuit diagram of a linearity-correcting circuit embodying the invention;

Figure 2 illustrates the amplitude envelope of a staircase test signal in a colour television transmission;

Figure 3 illustrates the differential, with respect to time, of a portion of the demodulated test signal of Figure 2;

Figure 4 is a graph of output amplitude against input amplitude for the circuit of Figure 1; and

Figure 5 is a circuit diagram of a further linearity-correcting circuit embodying the invention.

The linearity-correcting circuit of Figure 1 forms part of an intermediate frequency corrector unit in a colour television transmission chain. In this example, the colour video signal is used to modulate a 38.9 MHz carrier signal using amplitude modulation. The amplitude-modulated signal is filtered in a vestigial side band filter and then predistorted in the intermediate frequency corrector unit to compensate for the distortions which are anticipated to occur in the later stages of the transmission chain. The corrected signal is then mixed with a carrier wave from a heterodyne oscillator to produce an RF siqnal which is amplified and then delivered to a power amplifier, for example a klystron, for transmission from an antenna at, for example, 40 kW.

The intermediate frequency corrector unit, operating at intermediate frequency, remains band-independent and channel-independent, and consequently the same correction circuits can be used in many different applications. The intermediate frequency corrector unit includes circuits which compensate for differential phase distortion and differential gain distortion, which are described for example in our UK Patent No. 2153173 and our US Patent No. 4604589, but which are not illustrated or described in the present specification.

With reference to Figure 1, the vision intermediate frequency signal, at an amplitude V_{in}, is input to a linearity-correcting circuit, whose output amplitude V_{out}, having undergone a pre-distortion appropriate for the required linearity correction, is provided to other correction circuits of the intermediate frequency corrector unit.

The input voltage V_{in} is applied to the base of a transistor TR_1 whose collector is connected to a +12 volts supply by way of a transformer T whose other winding provides the output signal V_{out}. The emitter of transistor TR_1 is connected to a -12 volts supply potential by way of an inductance L1 and resistance R1, for D.C. biasing, and to earth by way of a blocking capacitor C1 and a gain-control resistor R_g.

Several, in this case five, alternative current paths between the emitter of transistor TR_1 and the -12 volts supply are provided in parallel by an array 11 of current sources I_1 to I_5 controlled by an array 10 of diodes. Each current source I_1 (I_2, I_3, I_4, I_5) is connected via a corresponding diode D11 (D21, D31, D41, D51) to a corresponding different supply potential V1 (V2, V3, V4, V5); and also to the emitter of transistor TR_1 via a respective diode D1 (D2, D3, D4, D5) whose polarity is reversed with respect to the first-mentioned diode. The supply potentials V1 to V5 form a regular series of increasing levels, selected in accordance with levels of the staircase steps of an inserted test signal (described below), and in this example are respectively 7.1 volts, 8.1 volts, 9.1 volts, 10.1 volts and 11.1 volts. The centre level VO is 6.0 volts.

Current source I_1 draws current through diode D11 when the transistor emitter voltage is lower than V1, but through diode D1 when the emitter voltage is above V1. The other current sources I2 to I5 operate in a similar manner; thus, when the emitter voltage exceeds V5, all five current sources draw current from the transistor emitter. The current i1 (i2, i3, i4, i5) provided by the respective current source I1 (I2, I3, I4, I5) is effectively added to the transistor collector current I_c, which in turn determines the amplitude of the output signal V_{out}. Thus pre-distortions are introduced in discrete steps over 5 amplitude bands. The current sources I1 to I5 are all independently variable, either manually or, preferably, under microprocessor control, in response to the varying amplitude characteristic of the transmission signal provided by the power amplifier, to provide the correct levels of pre-distortion to compensate for the distortion in the power

amplifier.

Colour television transmissions conventionally include an inserted test transmission (mentioned above) comprising a synchronisation pulse followed by a staircase, one in every field of the transmitted signal, as shown in Figure 2. The staircase portion comprises six amplitude levels joined by nearly vertical slope portions S_1, S_2, S_3, S_4 and S_5 respectively, whose mid-points have potentials V1, V2, V3, V4 and V5. These slope portions are nominally of the same gradient and height. The colour subcarriers are not shown. This test transmission is used to monitor the linearity of the transmitter chain by observing the effect of the power amplifier on the slopes S_1 to S_5 of the test signal. The slopes vary in proportion to the change in the rate of change of output amplitude with input amplitude, i.e. they represent the degree of non-linearity, at the relevant amplitude band. This monitoring is conventionally performed by feeding back the transmission signal, either from the power amplifier output or from a television receiver, to a control circuit which demodulates and then differentiates, with respect to time, the staircase portion of the test signal, the result of which is shown in Figure 3. In Figure 3, peaks P_1 to P_5 correspond respectively to slopes S_1 to S_5, and are nominally of the same height H. Distortion in the power amplifier is manifested by a deviation of one or more of these peaks from the expected height H: in Figure 3, peaks P_3, P_4 and P_5 are slightly lower than the expected level H, indicating that a pre-distortion is required in the linearity-correcting circuit of the transmitter chain.

The linearity-correcting circuit of Figure 1 is capable of correcting for non-linearity over any one of the five voltage bands centred at V1, V2, etc., independently of all the other voltage bands, simply by varying the corresponding current source independently of the other current sources in the bank 11 of current sources. Firstly, the circuit detects the levels of the steps of the staircase, computes the mid-slope levels V1 to V5, and then sets the supply potentials of the diode bank 10 accordingly. Then in order to correct the linearity over the voltage band centred at V3, for example, the peak P_3 is compared with the nominal level H, and the current source I3 is adjusted in accordance with the difference, in a direction such as to minimise that difference. In this example, peak P_3 is too low, and accordingly the current i_3 of current source I3 is increased accordingly. Subsequent test signals are again monitored, and the whole process repeated; any residual error in the height of peak P_3 is again corrected by a further change in current source I3.

The effect of such a correction on the output amplitude V_{out} for the expected range of input amplitudes V_{in} is illustrated diagrammatically in Figure 4. It is assumed, in the example of Figure 4, that the transmitter chain is perfectly linear over most input voltages, as represented by portions c_1 and c_3 of the graph. By increasing the current source I3, however, the slope c_2 of the graph near input voltage V3 is increased, so as to introduce the appropriate amount of pre-distortion. It will be appreciated that the width V_w of the band over which the slope c_2 is changed need not necessarily be equal to the difference between the steps of the staircase adjacent voltage V_3, so long as the mean rate of change of voltage is changed appropriately over that band; the value of V_w will depend on the forward drop of the diodes D3 and D31. The nominal slope c_1 is determined by the value of the resistor R_g. The value of the increase V_i in output voltage caused by the adjustment is determined by the current i_3 and the effective A.C. load seen by the collector of TRI, which is set by the load on the transformer and its turns ratio.

In existing linearity-correcting circuits which do not employ current sources for individual voltage bands, the slope in Figure 4 for the higher voltage bands would also vary as a result of the adjustment made for the band centred at V3, and the slope c_3 might instead be the slope c'_3 as shown in broken lines. This would then necessitate corresponding corrections for input voltages centred at V4 and above.

The second, and preferred embodiment of the invention will now be described with reference to Figure 5. The linearity-correcting circuit of Figure 5 comprises two circuits of the type shown in Figure 1, and similar parts are given the same reference numerals.

The transistor TR_1, diode bank 10 and current source array 11, resistor Rg, resistance R1 and inductance L1 are the same as the corresponding components of the circuit of Figure 1. A similar second circuit, comprising transistor TR_2, diode bank 101, current source array 111, bias resistor R'_g, resistance R'1 and inductance L'1, is connected in parallel. The collectors of the two transistors are connected across the output transformer T, to which the +12 volts supply is connected at a central tapping point. The current sources are switched individually in a switch control unit 12 such that, for each of the 5 amplitude bands, the appropriate current source in either array 11 or array 111, but not both, is connected to the -12 volts level.

A detector 200 receives an output signal from the power amplifier and processes the signal to determine the amplitude envelope resulting from the staircase portion of the test transmissions. This amplitude envelope is then fed to a control processor 300 which differentiates the envelope to derive

the levels of the peaks P_{12} to P_{56} (Figure 3), and to determine what changes are required to one or more of the currents "injected" by the current sources.

The current sources, in this example, are high resistances, of 18 kilo-ohms, connected to variable voltage sources, but alternatives would be active constant current circuits in series with chokes. The switch control unit 12 is a diagrammatic representation of the switching function, and in practice the switches are integrated with the current source arrays 11, 111. The diodes require rapid speed of operation and low forward drop, and in this example are hot carrier diodes; alternatively, however, they could be silicon diodes.

The two transistors TR_1 and TR_2 are driven such that the output voltage V_{out} depends on the difference between their collector currents by subtraction in the transformer T. This enables either positive or negative changes in the slopes to be made: the circuit of Figure 1 alone is not capable of reducing the slopes, i.e. reducing the rates of change of output voltage with input voltage. The magnitude of the change is determined, as before, by adjustment of the appropriate current source, by means of a signal from the control processor 300. The direction of the change is determined by switching on the appropriate current source either in bank 11 or in bank 111, using control signals sent to the switch control unit 12 from the control processor 300.

A further advantage of the circuit of Figure 5, compared with that of Figure 1, is that the effect of stray capacitance at the transistor emitters is reduced by the way in which the two transistor circuits are connected in anti-phase. Stray capacitance in the circuit of Figure 1 reduces the independence between the effects of the adjustment of the different current sources. Stray capacitance could be reduced further by integrating the whole linearity-correcting circuit on one chip.

The linearity-correcting circuits of Figures 1 and 5 do not require the baseband component of the input signal to be divided out, as is the case with many existing such circuits, but rather receives the intermediate frequency component and responds to its amplitude envelope. However, these circuits embodying the invention are still capable of operating at lower input signal frequencies, e.g. at video frequency or even down to D.C. (provided that a resistance were used in place of the transformer T).

Although the invention has been illustrated in the context of television transmission, it has many other applications. The invention may be used for linearity correction in any system whose output is nominally proportional to the input for a range of input amplitudes, and is not limited to amplitude-modulated carrier signals. The invention could, for example, be used in direct-current amplification, where a D.C. output signal potential is nominally proportional to that of a D.C. input signal.

Further, although the invention has been illustrated in the form of a linearity-correcting circuit, the invention could be embodied in a circuit for test purposes which deliberately introduces linearity distortion into a signal, for example to simulate a particular power-amplifier. Indeed, the principle of the invention is applicable to circuits in which the output amplitude is not necessarily nominally proportional to the input amplitude, for example circuits for synthesising any desired gain-amplitude profile.

Claims

1. A linearity-adjusting circuit for adjusting the rate of change of amplitude of an output signal with respect to the amplitude of an input signal from which the output signal is derived, comprising, for each of several bands of the input signal amplitude: means (11) for selectively introducing a differential voltage to the output signal amplitude over that amplitude band, means (TR1) for amplifying the input signal to derive the output signal, the differential voltage introducing means (11) being coupled to the amplifying means (TR1) for adjustment of the gain of the amplifying means as a function of the input signal amplitude; and control means (12, 200, 300) coupled to the differential voltage introducing means (11) for selecting over which amplitude bands to introduce such differential voltages and for determining the magnitudes of such differential voltages, to achieve a predetermined linearity variation for the whole amplitude range, characterised in that the differential voltage introducing means (11) comprises a plurality of adjustable constant current sources (I_1 - I_5) each arranged to introduce to the amplifying means (TR1) a differential current over a predetermined respective input signal amplitude band, such that the mean rate of change of amplitude of the output signal with respect to the amplitude of the input signal is changed only over that amplitude band;

2. A circuit according to Claim 1, characterised in that the output signal amplitude is nominally proportional to the input signal amplitude.

3. A circuit according to Claim 1 or 2 characterised in that the input signal comprises an amplitude-modulated carrier, the amplitude of whose modulation envelope determines the

gain of the amplifying means.

4. A circuit according to claims 1, 2 or 3 characterised in that each adjustable constant current source (I_1 to I_5) is connected to the amplifying means (TR1) via a respective diode (D_1 - D_5) which is coupled to a voltage source (V_1 - V_5) at such a level that the diode (D_1 - D_5) is biased into conduction only when the input signal has reached its said predetermined amplitude.

5. A transmitter chain comprising a linearity-adjusting circuit according to any preceding claim and including means (200) for detecting the amplitude of the transmitted signal, and control means (300) responsive to the said detecting means for setting the levels of the said differential voltages so as to introduce an appropriate pre-distortion to correct the linearity.

Patentansprüche

1. Ein Linearitätseinstellschaltkreis zum Einstellen der Änderungsrate der Amplitude eines Ausgangssignals bezüglich der Amplitude eines Eingangssignals, von welchem das Ausgangssignal abgeleitet wird, der für jedes von mehreren Bändern der Eingangssignalamplitude umfaßt: Mittel (11), um selektiv eine Differentialspannung zur Ausgangssignalamplitude über dieses Amplitudenband einzuführen, Mittel (TR1), um das Eingangssignal zu verstärken und somit das Ausgangssignal abzuleiten, wobei die Differentialspannungs-Einführungsmittel (11) an die Verstärkungsmittel (TR1) gekoppelt sind für eine Einstellung der Verstärkung der Verstärkungsmittel als eine Funktion der Eingangssignalamplitude, und Steuerungsmittel (12, 200, 300), die an die Differentialspannungs-Einführungsmittel (11) gekoppelt sind, um auszuwählen, über welche Amplitudenbänder solche Differentialspannungen einzuführen sind, und um die Größen solcher Differentialspannungen zu bestimmen, und somit eine vorbestimmte Linearitätsveränderung für den gesamten Amplitudenbereich zu erzielen,
dadurch gekennzeichnet,
daß das Differentialspannungs-Einführungsmittel (11) eine Vielzahl von einstellbaren konstanten Stromquellen (I_1 -I_5) umfaßt, von denen jede angeordnet ist, um zu den Verstärkungsmitteln (TR1) einen Differentialstrom über ein vorbestimmtes jeweiliges Eingangssignalamplitudenband einzuführen, so daß die mittlere Rate einer Amplitudenänderung des Ausgangssignals bezüglich der Amplitude des Eingangssignals lediglich über dieses Amplitudenband geändert wird.

2. Ein Schaltkreis nach Anspruch 1,
dadurch gekennzeichnet,
daß die Ausgangssignalamplitude nominell proportional zur Eingangssignalamplitude ist.

3. Ein Schaltkreis nach Anspruch 1 oder 2,
dadurch gekennzeichnet,
daß das Eingangssignal einen amplitudenmodulierten Träger umfaßt, wobei die Amplitude seiner Modulations-Einhüllenden die Verstärkung der Verstärkungsmittel bestimmt.

4. Ein Schaltkreis nach den Ansprüchen 1, 2 oder 3,
dadurch gekennzeichnet,
daß jede einstellbare konstante Stromquelle (I_1 bis I_5) mit den Verstärkungsmitteln (TR1) über eine jeweilige Diode (D_1 - D_5) verbunden ist, die an eine Spannungsquelle (V_1 - V_5) bei solch einem Niveau verbunden ist, daß die Diode (D_1 - D_5) nur dann in einen leitenden Zustand vorgespannt wird, wenn das Eingangssignal seine vorbestimmte Amplitude erreicht hat.

5. Eine Senderkette mit einem Linearitätseinstellschaltkreis nach einem der vorhergehenden Ansprüche und mit Mitteln (200) zum Nachweisen der Amplitude des übertragenen Signals und Steuerungsmitteln (300), die empfänglich für die Nachweismittel sind, um die Niveaus der Differentialspannungen einzustellen und somit eine geeignete Vorverzerrung einzuführen, um die Linearität zu korrigieren.

Revendications

1. Circuit de réglage de linéarité pour régler le rapport de variation d'amplitude d'un signal de sortie par rapport à l'amplitude d'un signal d'entrée à partir duquel le signal de sortie est obtenu, comprenant, pour chacune de plusieurs bandes d'amplitudes du signal d'entrée : un moyen d'introduction d'une tension différentielle (11) pour introduire de manière sélective une tension différentielle dans l'amplitude du signal de sortie sur cette bande d'amplitudes ; un moyen d'amplification (TR1) pour amplifier le signal d'entrée pour obtenir le signal de sortie, le moyen d'introduction d'une tension différentielle (11) étant relié au moyen d'amplification (TR1) pour le réglage du gain du moyen d'amplification en fonction de l'amplitude du signal d'entrée ; et un moyen de commande (12, 200, 300), connecté au moyen

d'introduction d'une tension différentielle (11), pour choisir sur quelles bandes d'amplitudes introduire de telles tensions différentielles et pour déterminer les amplitudes de ces tensions différentielles, pour obtenir une variation de linéarité prédéterminée pour l'ensemble de la gamme d'amplitudes ; caractérisé en ce que le moyen d'introduction d'une tension différentielle (11) comprend une pluralité de sources de courant constant réglables (I_1 à I_5) agencées chacune pour introduire dans le moyen d'amplification (TR1) un courant différentiel sur une bande d'amplitudes de signal d'entrée respective prédéterminée, de telle manière que le rapport moyen de variation d'amplitude du signal de sortie par rapport à l'amplitude du signal d'entrée soit modifié seulement sur cette bande d'amplitudes.

2. Circuit selon la revendication 1, caractérisé en ce que l'amplitude du signal de sortie est théoriquement proportionnelle à l'amplitude du signal d'entrée.

3. Circuit selon la revendication 1 ou 2, caractérisé en ce que le signal d'entrée comprend une porteuse modulée en amplitude, dont l'enveloppe de modulation en amplitude détermine le gain du moyen d'amplification.

4. Circuit selon les revendications 1, 2 ou 3, caractérisé en ce que chaque source de courant constant réglage (I_1 à I_5) est connectée au moyen d'amplification (TR1) par l'intermédiaire d'une diode (D_1 à D_5) respective qui est reliée à une source de tension (V_1 à V_5) à un niveau tel que la diode (D_1 à D_5) est polarisée de manière à être conductrice seulement lorsque le signal d'entrée a atteint son amplitude prédéterminée.

5. Chaîne d'émetteur comprenant un circuit de réglage de linéarité selon l'une quelconque des revendications précédentes et comprenant un moyen (200) pour détecter l'amplitude du signal émis, et un moyen de commande (300) sensible audit moyen de détection pour régler les niveaux desdites tensions différentielles de manière à introduire une préaccentuation appropriée pour corriger la linéarité.

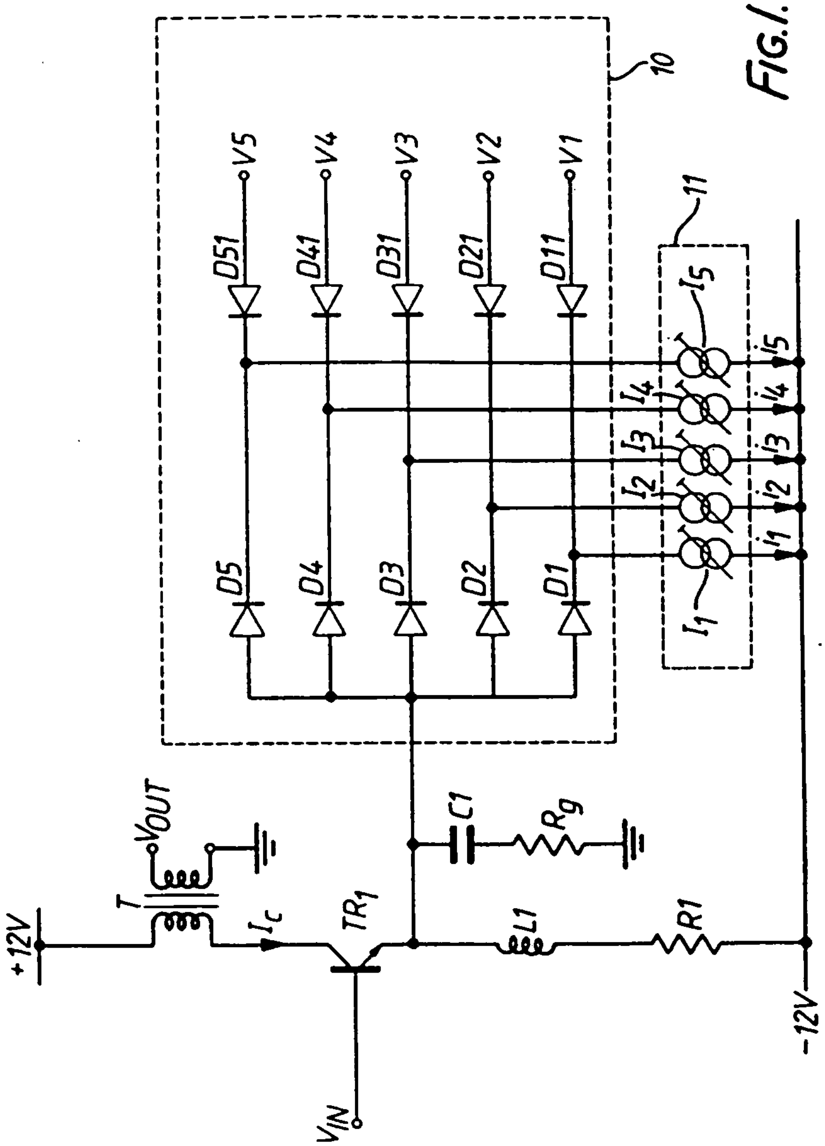
10
11
V5
V4
V3
V2
V1
D51
D41
D31
D21
D11
D5
D4
D3
D2
D1
I1
I2
I3
I4
I5
i1
i2
i3
i4
i5
+12V
-12V
T
VOUT
Ic
TR1
VIN
C1
Rg
L1
R1

FIG.1.

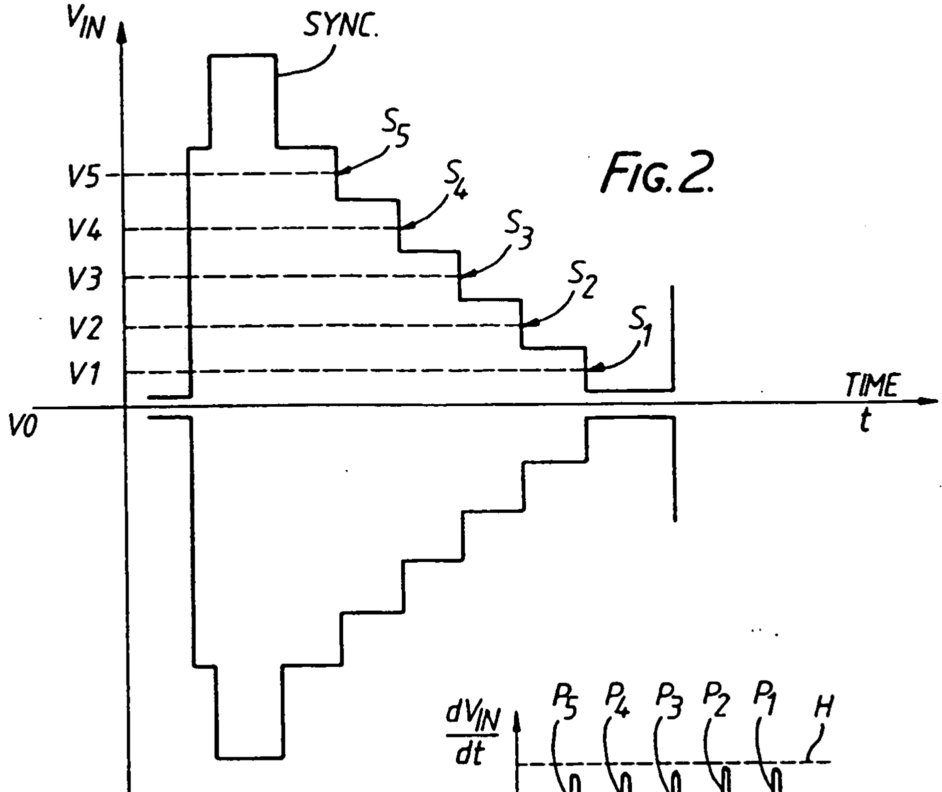

FIG.2.

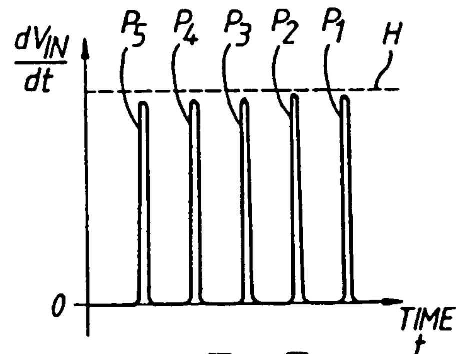

FIG.3.

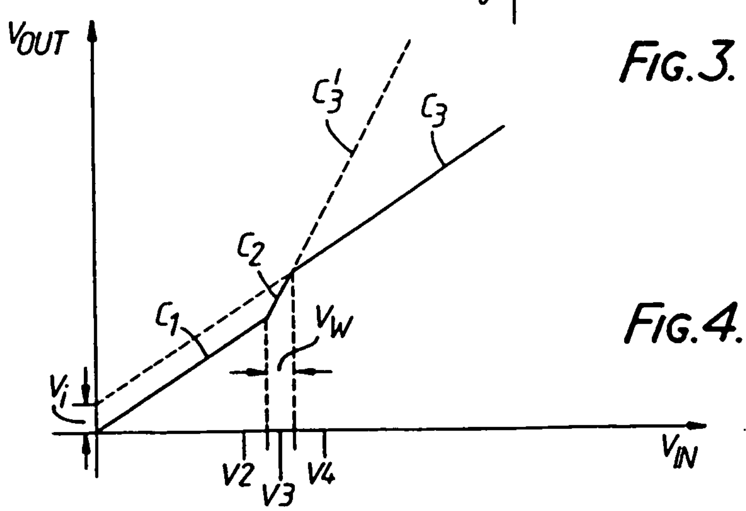

FIG.4.

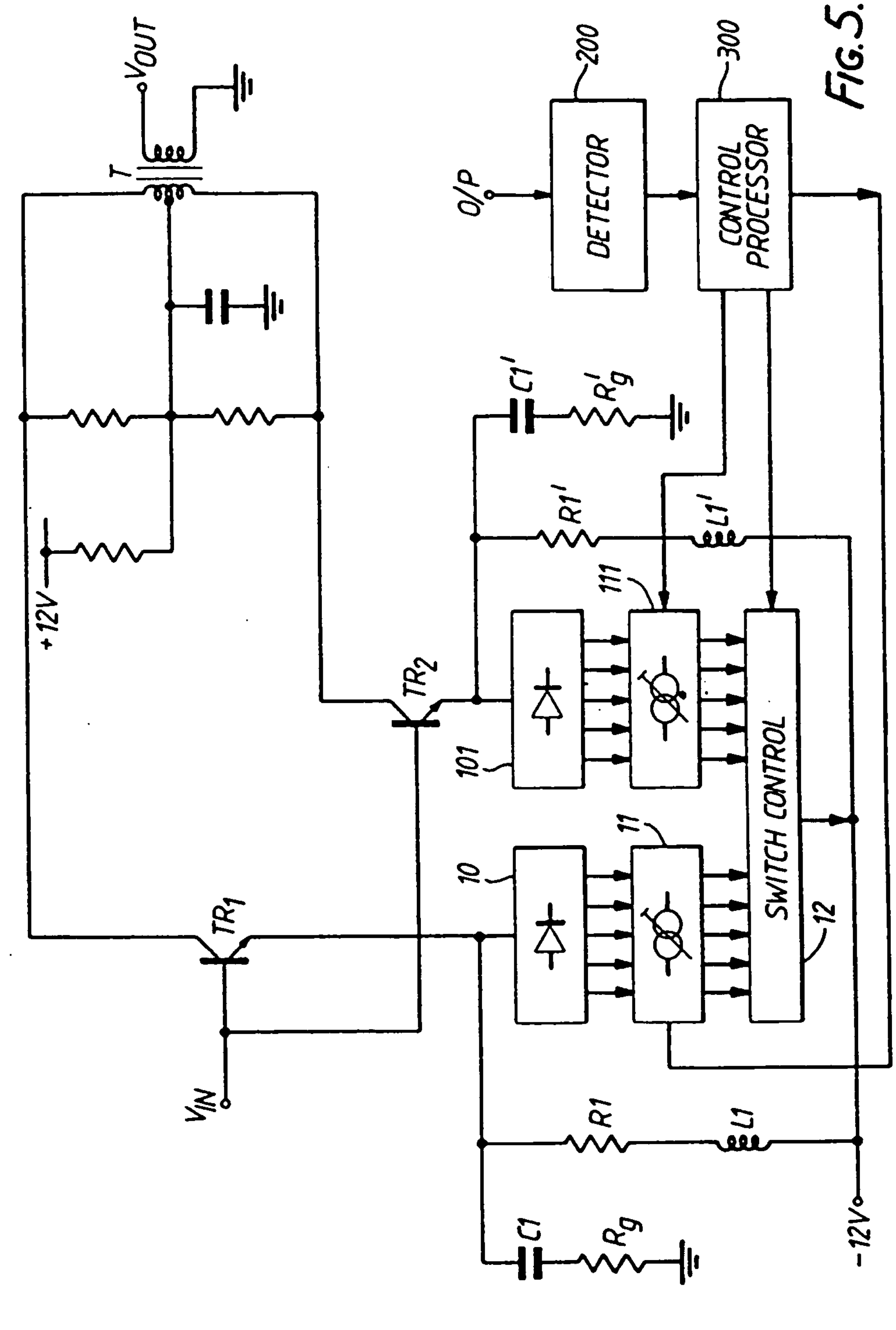
VOUT
T
+12V
TR1
TR2
VIN
O/P
DETECTOR
CONTROL PROCESSOR
200
300
C1'
Rg'
R1'
L1'
111
101
10
11
SWITCH CONTROL
12
R1
L1
C1
Rg
-12V

FIG. 5.